Watershed Scale Response to Climate Change—Clear Creek Basin, Iowa

Introduction

General Circulation Model (GCM) simulations of future climate through 2099 project a wide range of possible scenarios (Intergovernmental Panel on Climate Change, 2007). To determine the sensitivity and potential effects of long-term climate change on the freshwater resources of the United States, the U.S. Geological Survey Global Change study, “An integrated watershed scale response to global change in selected basins across the United States” was started in 2008. The long-term goal of this national study is to provide the foundation for hydrologically based climate-change studies across the nation.

Fourteen basins for which the Precipitation Runoff Modeling System (PRMS) has been calibrated and evaluated were selected as study sites. PRMS is a deterministic, distributed-parameter watershed model developed to evaluate the effects of various combinations of precipitation, temperature, and land use on streamflow and general basin hydrology. Output from five GCMs and four emission scenarios were used to develop an ensemble of climate-change scenarios for each basin. These ensembles were simulated with the corresponding PRMS model. This fact sheet summarizes the hydrologic effect and sensitivity of the PRMS simulations to climate change for the Clear Creek Basin near Coralville, Iowa (U.S. Geological Survey streamflow-gaging station 05454300; fig. 1) presented in the project summary report (Markstrom and others, 2012) and a journal article (Hay and others, 2011).

Study Area

The Clear Creek Basin is located in east-central Iowa, includes parts of Iowa and Johnson Counties, and is a tributary to the Iowa River. The basin is oriented in a general west-east direction and drains 254 square kilometers (km^2). The topography of the Clear Creek Basin is characterized by uplands dissected by tributary streams (Schwob, 1964). The Clear Creek Basin has a wide and broad flood plain, with a meandering channel except along reaches that have been straightened (Barnes and Eash, 1990). Land use predominantly is agricultural with a growing urbanization in Johnson County, Iowa. The Iowa Department of Natural Resources (IDNR) and the Natural Resources Conservation Service (NRCS) created the Clear Creek Watershed Enhancement Project (Iowa Department of Natural Resources, 2011). The goal of this project is to use data from U.S. Geological Survey streamflow-gaging stations 05454220 and 05454300 in decisionmaking that will help restore Clear Creek water-quality to natural conditions.

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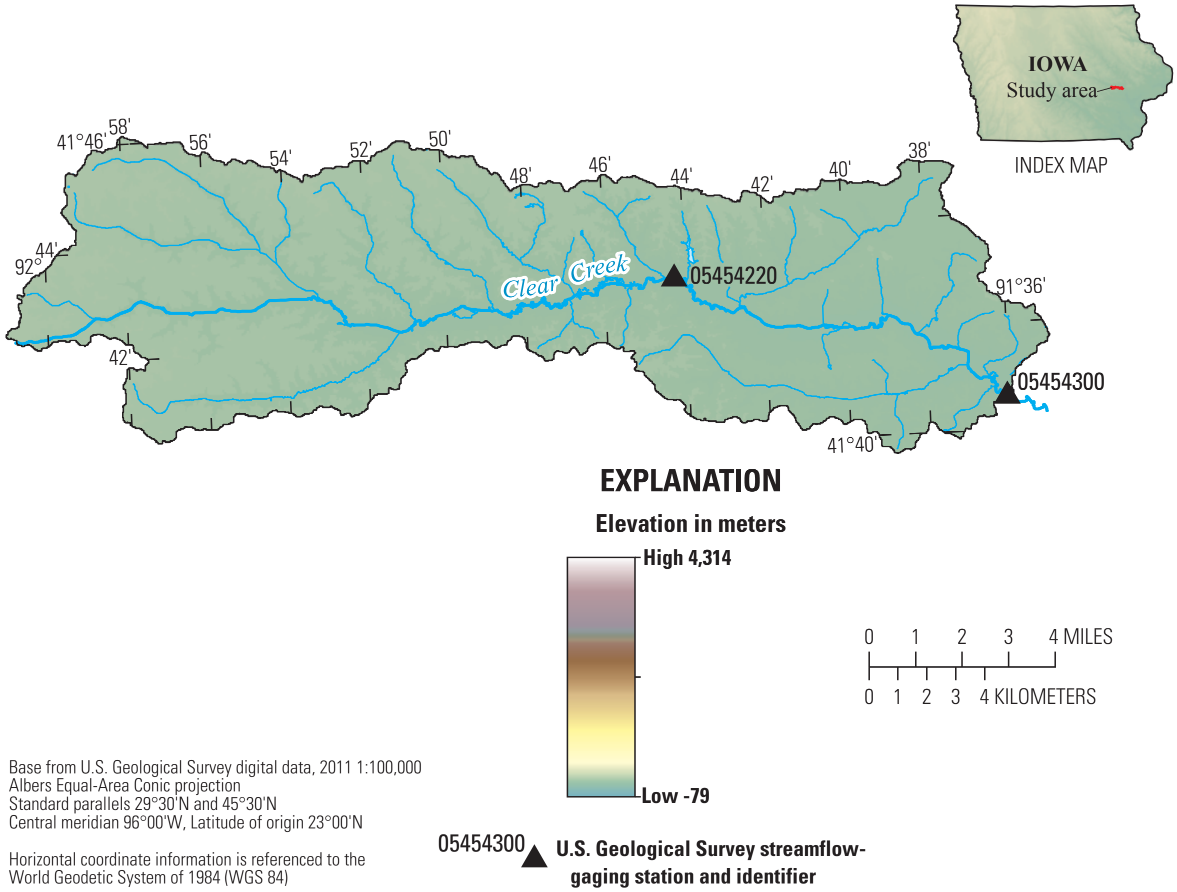

Figure 1. Precipitation Runoff Modeling System study locations, Clear Creek Basin, Iowa, and location of U.S. Geological Survey streamflow gaging station 05454300 with a drainage area of 254 square kilometers and elevation range from 205 to 261 meters.

General Circulation Models

General Circulation Models

Given the uncertainty in climate modeling, it is desirable to use more than one GCM to obtain a range of potential future climatic conditions. Monthly precipitation and temperature output from five GCMs were processed (table 1).

Table 1. General Circulation Model (GCM) projections used in this study.

GCM	Center and country of origin
BCC–BCM2.0	Bjerknes Centre for Climate Research, Norway
CSIRO–Mk3.0	Australia’s Commonwealth Scientific and Industrial Research Organization, Australia
CSIRO–Mk3.5	Australia’s Commonwealth Scientific and Industrial Research Organization, Australia
INM–CM3.0	Institute for Numerical Mathematics, Russia
MIROC3.2	National Institute for Environmental Studies, Japan

The GCM outputs were obtained from the World Climate Research Programme's Coupled Model Intercomparison Project phase 3 multi-model dataset archive, which was referenced in the Intergovernmental Panel on Climate Change Fourth Assessment Special Report on Emission scenarios (Intergovernmental Panel on Climate Change, 2007). For each GCM, one current (water years 1988–1999) and three future emission scenarios were used and are described in table 2.

Table 2. Climate-change emission scenarios simulated by the General Circulation Models in this study.

Emission scenario	Description/assumptions
20C3M	20th century climate used to determine baseline (1989–1999) conditions
A1B	Rapid economic growth, a global population that peaks in mid-21st century and rapid introduction of new and more efficient technologies with a balanced emphasis on all energy sources
B1	Convergent world, with the same global population as Emission scenario A1B, but with more rapid changes in economic structures toward a service and information economy that is more ecologically friendly
A2	Heterogeneous world with high population growth, slow economic development, and slow technological change

Climate-change fields were derived by calculating the change in climate from current (water years 1988–1999) to future conditions simulated by each GCM. The 20C3M simulation for water years 1988–1999 was used to represent current climatic conditions. This 12-year period of record was chosen based on the overlap of the available historical records from the 14 basins included in the national study. Climate change fields (percentage changes in precipitation and degree changes in temperature) were computed for 12-year moving window periods (from 2001–2099) using the 20C3M (1988–1999) and the A1B, B1, and A2 emission scenarios. A 12-year moving window, starting in 2001 and ending in 2099, results in 1,320 future scenarios [(88, 12-year climatologies, 1 per year starting with 2001–2012 and ending with 2088–2099) x (3 emission scenarios) x (5 GCMs)].

Climate-change scenarios were generated for PRMS by modifying PRMS precipitation and temperature inputs with the mean monthly climate change fields derived from the GCMs, resulting in 1,320 PRMS-input files. Table 3 shows the change (slope) and adjusted R^2 (adjR2) for the least squares fit to the trend line for selected output variables from the PRMS projections. The slope indicates the change in the selected variable by year. The adjusted R^2 value gives an indication of the variability in the central tendency of the trend line.

Figure 2 shows a summary of the projected range in 11-year moving mean daily values of maximum temperature (fig. 2*A*), minimum temperature (fig. 2*B*), and precipitation (fig. 2*C*) by emission scenario. The first year of each 12-year simulation was used as PRMS initialization and is not included in the results. The three solid-colored lines indicate the 11-year moving mean values (x-axis indicates center of 11-year window) for the three future emission scenarios (central tendency of the five GCMs for each emission scenario). The projected range shown for each emission scenario indicates the range of potential future climatic conditions simulated by the five GCMs. All GCM simulations project steady increases in maximum and minimum temperature (table 3), with uncertainties associated with these GCM projections increasing with time. Both maximum and minimum temperatures show the smallest projected changes for the B1 scenario. The wide range and lack of significant trend in the precipitation projections indicates a large amount of uncertainty in the GCM scenarios used in this study (table 3).

Results

PRMS simulates spatially distributed streamflow, components of flow (surface, subsurface, and groundwater), snowpack conditions, and many other hydrologic components of interest. Figure 3 shows the projected range in 11-year moving mean daily values of streamflow (fig. 3*A*) and the component of flow (figs. 3*B*–3*D*) by emission scenario. The central tendencies of the PRMS simulations using the three emission scenarios project decreases in mean annual streamflow for the A1B and A2 emission scenarios (table 3), though the uncertainties associated with these streamflow projections are large. In general, projections of surface, subsurface, and groundwater flow indicate the same decreasing pattern as the annual mean streamflow.

Changes in precipitation can be examined on a monthly basis (fig. 4). The solid red lines in figure 4 show PRMS-simulated mean monthly baseline conditions (1989–1999) for precipitation. The box plots represent the range in the mean monthly outputs for the five GCMs and three future emission scenarios for 2030 (green, 2025–2035), 2060 (tan, 2055–2065) and 2090 (blue, 2085–2095). Projections indicate that the months associated with the lowest precipitation amounts (September through April) have minimal changes with low variability. In contrast, the months associated with the highest precipitation amounts (May through August) show both increasing and decreasing precipitation with much larger uncertainties.

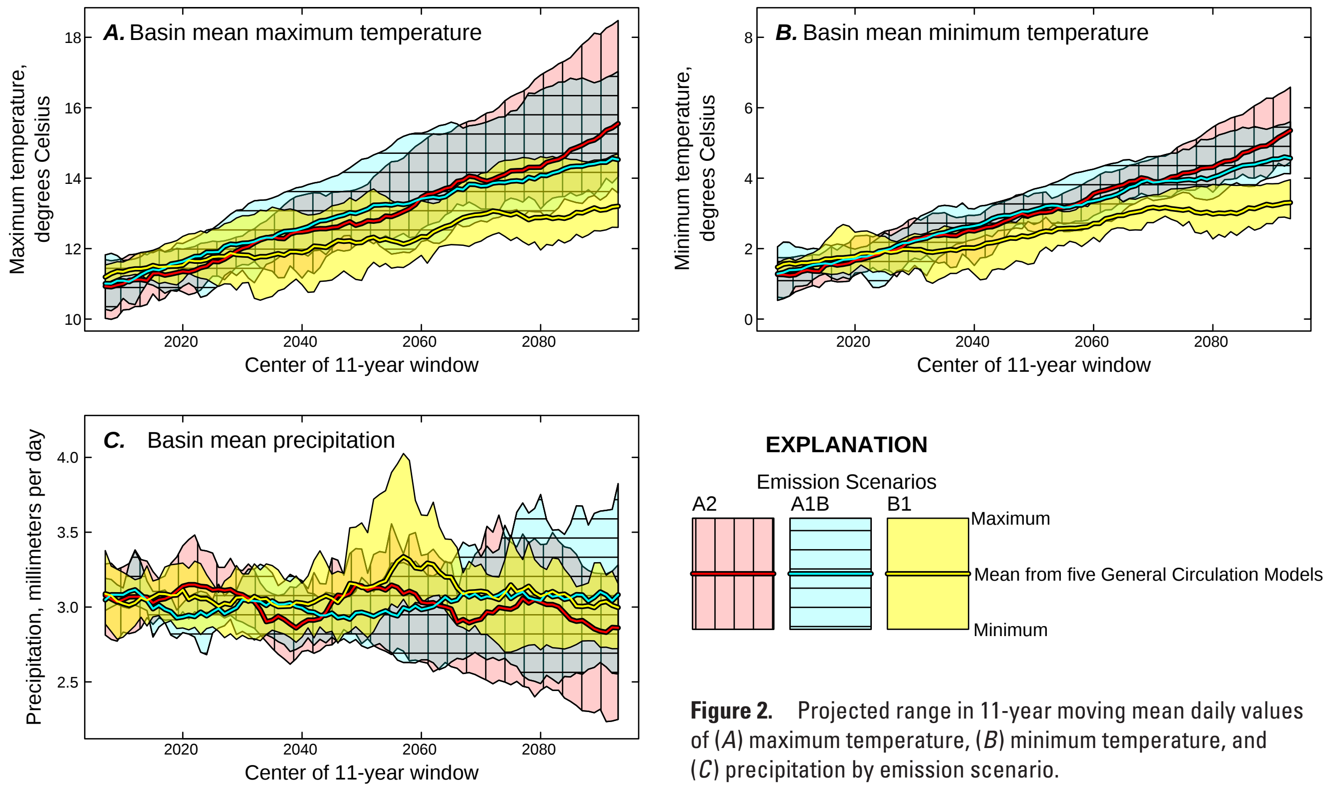

Figure 2. Projected range in 11-year moving mean daily values of (*A*) maximum temperature, (*B*) minimum temperature, and (*C*) precipitation by emission scenario.

Table 3. Projected change by year (slope) and adjusted R^2 (adjR2) based on the central tendencies of the five General Circulation Models for the three carbon emission scenarios for selected Precipitation Runoff Modeling System (PRMS) output variables.

[Blue indicates a significant negative trend and yellow indicates a significant positive trend (p<0.05) accounting for lag-1 autocorrelation]

PRMS output variable	Emission scenario A1B		Emission scenario A2		Emission scenario B1	
	slope	adjR2	slope	adjR2	slope	adjR2
Maximum temperature in degrees Celsius	0.041	0.99	0.051	0.99	0.023	0.96
Minimum temperature in degrees Celsius	0.039	0.99	0.046	0.99	0.022	0.96
Precipitation in millimeters per day	0.0008	0.14	-0.0018	0.25	0.0006	0.02
Streamflow in cubic meters per second	-0.0101	0.73	-0.0169	0.86	-0.0065	0.48
Surface runoff in cubic meters per second	-0.00213	0.64	-0.00396	0.79	-0.00125	0.26
Subsurface flow in cubic meters per second	-0.00448	0.71	-0.00745	0.84	-0.00311	0.53
Groundwater flow in cubic meters per second	-0.00349	0.80	-0.00550	0.91	-0.00217	0.57
Soil moisture in millimeters per day	-0.3386	0.93	-0.5071	0.95	-0.1537	0.55

Related streamflow variables produced by PRMS are summarized in Markstrom and others (2008). Analysis of these intermediate states may indicate areas of the water balance most susceptible to changes in climate. For example, figure 5 shows the projected change in simulated basin mean annual values of soil moisture, an important indicator variable for effect in agricultural regions. The central tendency for the A1B and A2 emission scenarios shows a decrease in soil moisture over time (table 3). Based on these results, the likelihood of an increase in annual mean soil moisture are minimal. However, the uncertainty associated with decreasing soil moisture increases over time.

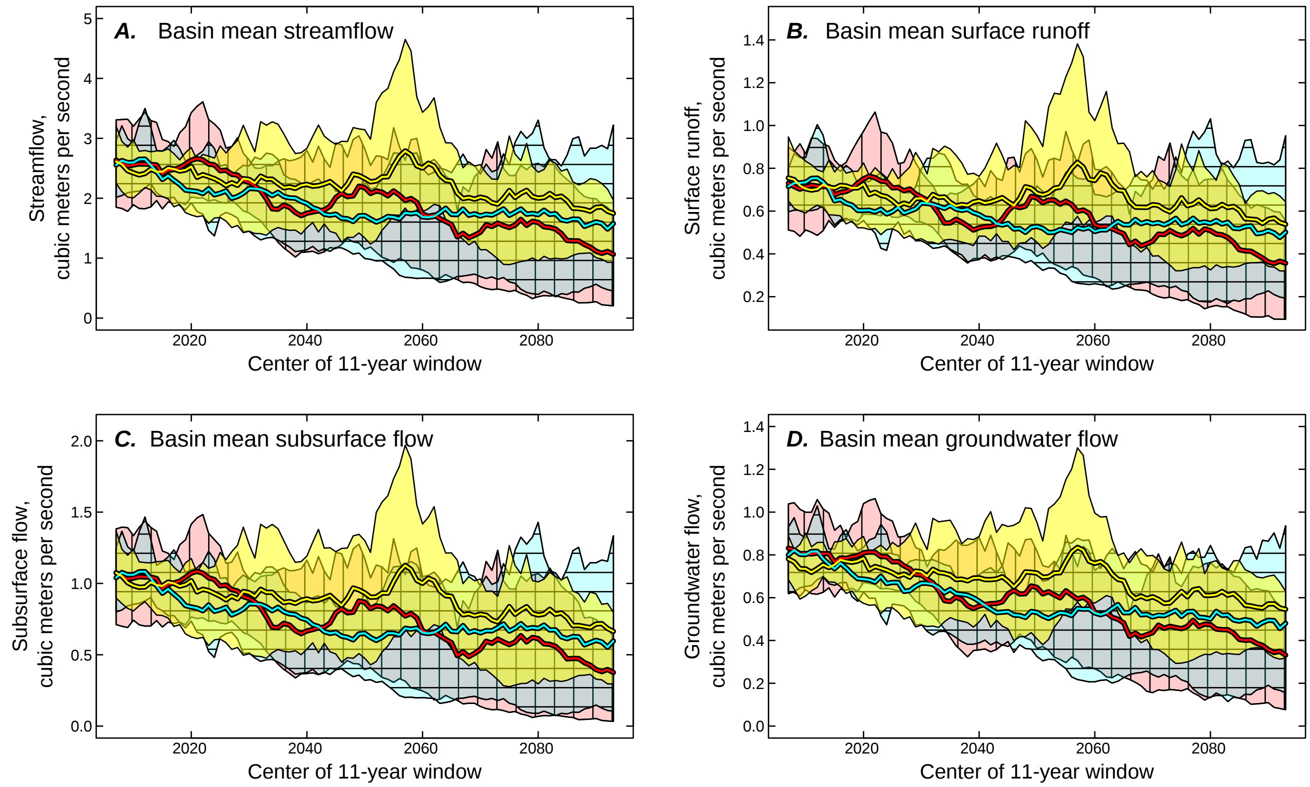

Figure 3. Projected range in 11-year moving mean daily values of (*A*) streamflow, (*B*) surface runoff, (*C*) subsurface flow, and (*D*) groundwater flow by emission scenario.

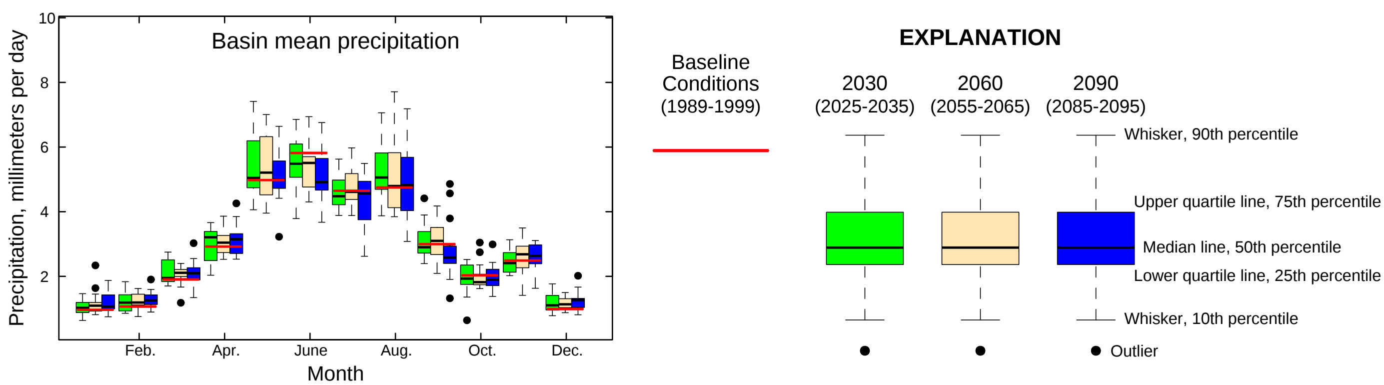

Figure 4. Mean daily precipitation values by month for baseline conditions and projected range (2030, 2060, and 2090) using the five General Circulation Models and three emission scenarios.

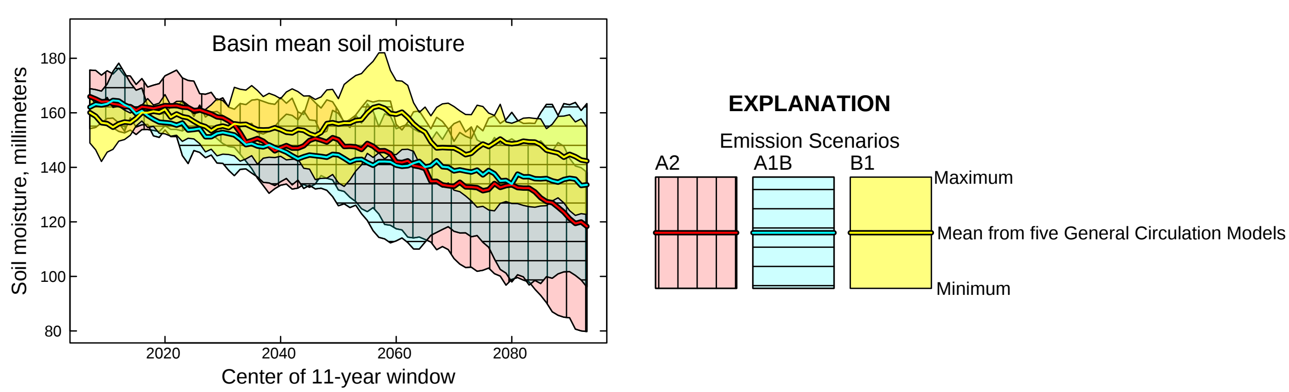

Figure 5. Projected range in 11-year moving mean daily values of soil moisture by emission scenario.

Conclusion and Discussion

In the Clear Creek Basin, agricultural water consumption and population growth will result in increasing water demand. The broader-scale effects of climate change on the flow regime of the Clear Creek Basin indicates an overall slight drying of the basin as a consequence of increased evapotranspiration, but the uncertainty associated with the magnitude of this drying is large.

These results did not consider potential future population growth and land-use changes. They also do not answer the question of whether the potentially adverse effects because of climate change can be mitigated with careful land-use planning in the Clear Creek Basin.

The combined effects of climate change and urbanization in the Clear Creek Basin may alter both the quantity and timing of streamflow and have the potential to change the conditions of water- quality that supports biological diversity in aquatic communities. The scientific techniques described in the fact sheet can be augmented with other techniques in developing the science needed to address the combined effects of climate and land-cover dynamics on streamflow regimes.

Selected References

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